WORLD METEOROLOGICAL ORGANIZATION | GLOBAL ATMOSPHERE WATCH | WWRP WORLD WEATHER RESEARCH PROGRAMME

No. 7 – SEPTEMBER 2023

WMO AIRBORNE DUST BULLETIN

Overview of global airborne dust in 2022

The global average of annual mean dust surface concentrations in 2022 (13.8 μg m^{-3}, see Figure 1(a)) was slightly higher than that in 2021 (13.5 μg m^{-3}, see *WMO Airborne Dust Bulletin, No. 6*). This increase in 2022 is mainly attributed to enhanced dust emissions from several dust-active regions around the world, such as west-central Africa, the Arabian Peninsula, the Iranian Plateau and north-western China. Spatially, the estimated peak annual mean dust surface concentration (~900–1 200 μg m^{-3}) in 2022 was located in some areas of Chad in north-central Africa. In the southern hemisphere, dust concentrations reached their highest level (~200–300 μg m^{-3}) in parts of central Australia and the west coast of South Africa. Wind-driven dust aerosols may be transported from these typical dust source areas to many regions of the world, over distances of hundreds to thousands of kilometres. The regions that are most vulnerable to long-range transport of dust are: the northern tropical Atlantic Ocean between West Africa and the Caribbean; South America; the Mediterranean Sea; the Arabian Sea; the Bay of Bengal; central-eastern China; the Korean Peninsula and Japan. In 2022, the transatlantic transport of African dust invaded the entire Caribbean Sea region and East Asian dust aerosols from the Gobi Desert also continued to reach the Bohai and Yellow Seas.

In the most affected areas, the surface dust concentration in 2022 was higher than the climatological mean. Exceptions to this were: parts of North Africa, including Senegal, Mauritania, Mali, eastern Algeria, Libya, and the central area of the border between Chad and Sudan; parts of Central Asia, including Iraq, Uzbekistan, and Kyrgyzstan; parts of East Asia, including north-central China and southern Mongolia; and mid-west Australia (Figure 1(b)). Hotspots with significantly higher dust concentrations were identified in Central and South America, most of Central Africa, Spain, the Red Sea, the Arabian Peninsula, the Arabian Sea, the Iranian Plateau, the Bay of Bengal, South Asia, the Tarim Basin in north-west China and the tropical Atlantic Ocean between West Africa and the Caribbean.

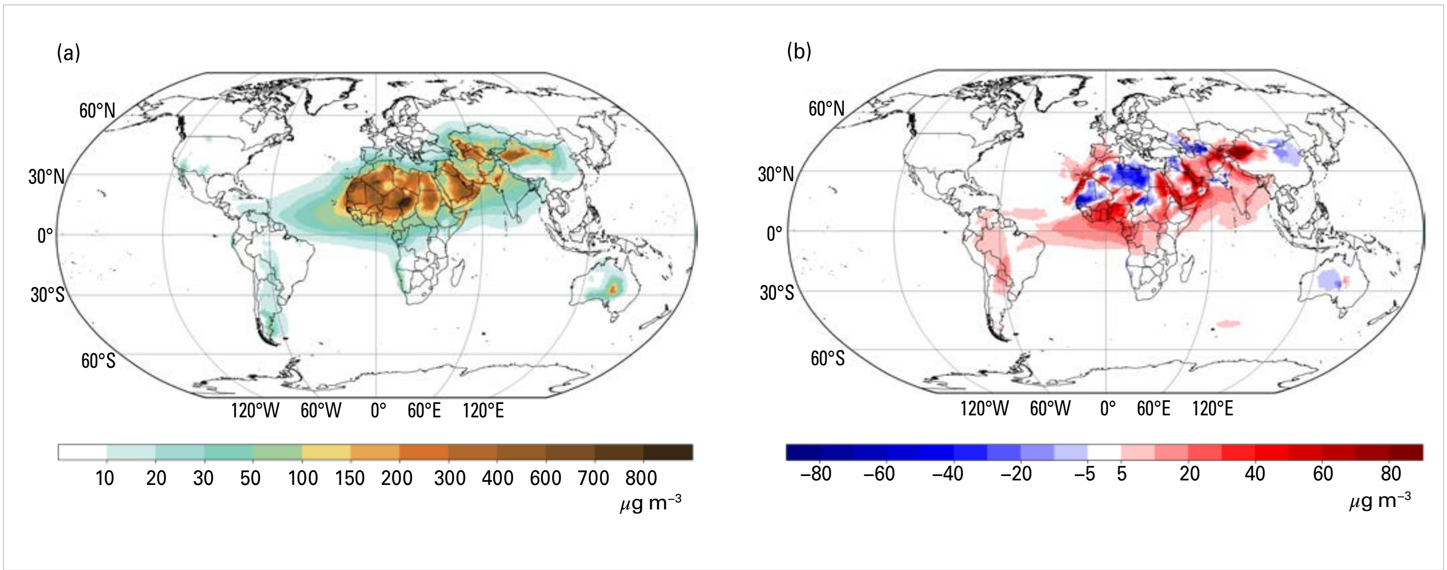

Figure 1. (a) Annual mean surface concentration of mineral dust (in μg m^{-3}) in 2022. (b) Anomaly of the annual mean surface dust concentration in 2022 relative to the 1981–2010 mean.

Source: These results are derived from the Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2) (Gelaro et al., 2017).

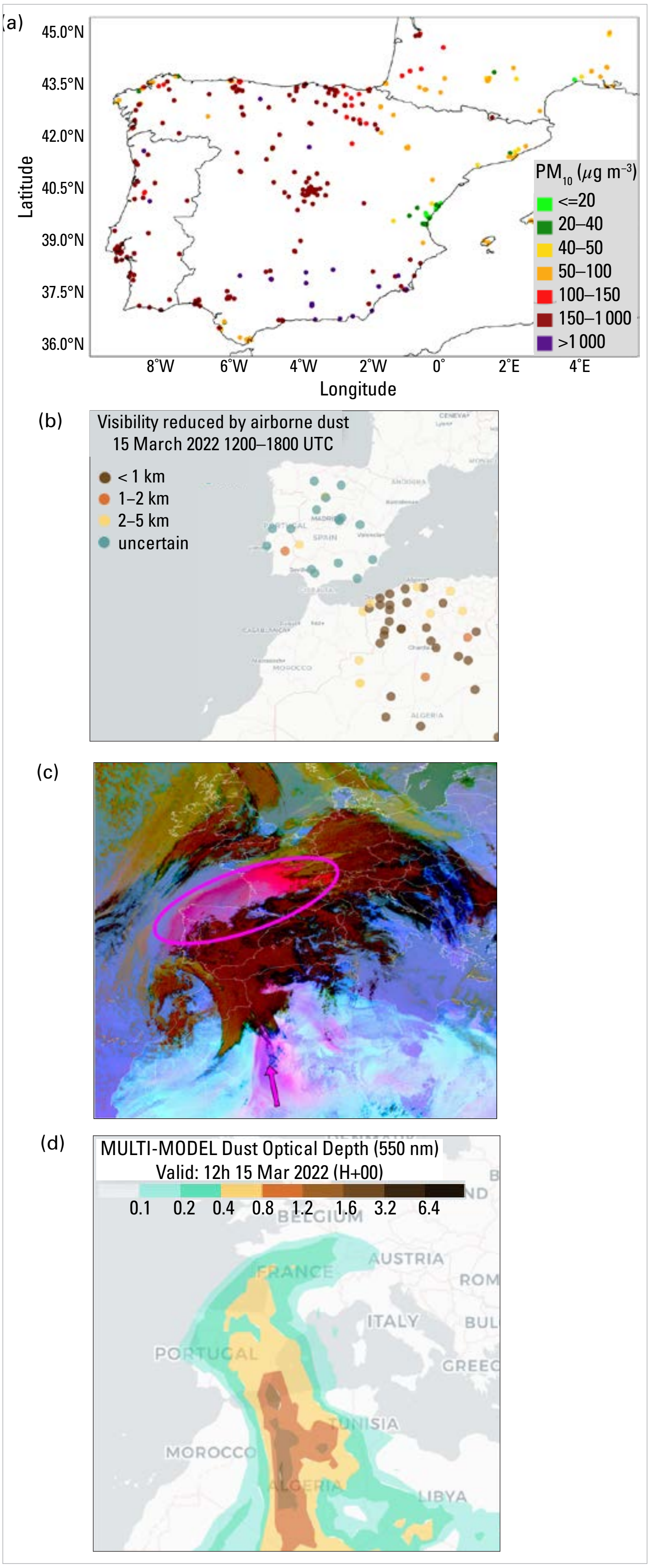

Figure 2. (a) Daily maximum values of PM_{10} for the period 24–31 March 2022. (b) Reduced visibility caused by dust and haze on 15 March 2022 at 1200 UTC. (c) The Meteosat RGB dust product for 15 March 2022 at 1200 UTC (dust is represented by the colour pink). The arrow points to the incoming dust, and the ellipse encircles the dust mass not covered by clouds. (d) Dust daily multimodel forecast product showing dust optical depth on 15 March 2022 at 1200 UTC.

Sources: (a) European Environment Agency; (b) WMO Barcelona Dust Regional Center: https://dust.aemet.es/; (c) EUMETSAT; (d) WMO Barcelona Dust Regional Center

Major sand and dust storm events in 2022

Widespread dust intrusion across Europe in March 2022

Starting on 14 March 2022, an exceptional dust outbreak was transported from northern Africa towards the Iberian Peninsula, spreading rapidly over Europe in the following days (see Figure 2). In many locations in Spain and Portugal, particulate matter (namely, PM_{10}) measurements exceeded the mean daily limit of 50 $\mu g\ m^{-3}$ established by European Union air quality regulations, with peak hourly values higher than 3 500 $\mu g\ m^{-3}$ in some stations in south-eastern Spain, such as El Ejido (Figure 2(a)). The Algerian Meteorological Service issued several warnings, from yellow to orange, concerning strong winds, sandstorms and heatwaves affecting most provinces, where health risks and hazardous driving conditions were highlighted. Visibility below 1 km was reported in Algeria during this event (Figure 2(b)). The event was accompanied by rain (see dark red cloud in Figure 2(c)); in fact, in some locations in Spain, wet deposition formed a layer of mud that had to be thoroughly removed to prevent slipping accidents.

The temporal and geographic extent of this dust event, (Figure 2(d)), and its exceptional intensity, were well-predicted by the multi-model ensemble dust forecast product of the WMO Barcelona Dust Regional Center. The Center's multimodel ensemble forecasted a maximum surface concentration of 1 500 $\mu g\ m^{-3}$. The predicted dust mass reached a vertical extension of 4.5 km above sea level, favouring the transport towards northern latitudes in Europe. Deposition over the Pyrenees (Figure 3) reflects the intensity of the event and its vertical extension, which left the tops of the mountain system clean.

A cut-off low pressure system south-west of the Iberian Peninsula, named *Celia* by the Portuguese Institute for Sea and Atmosphere (IPMA), generated an intense

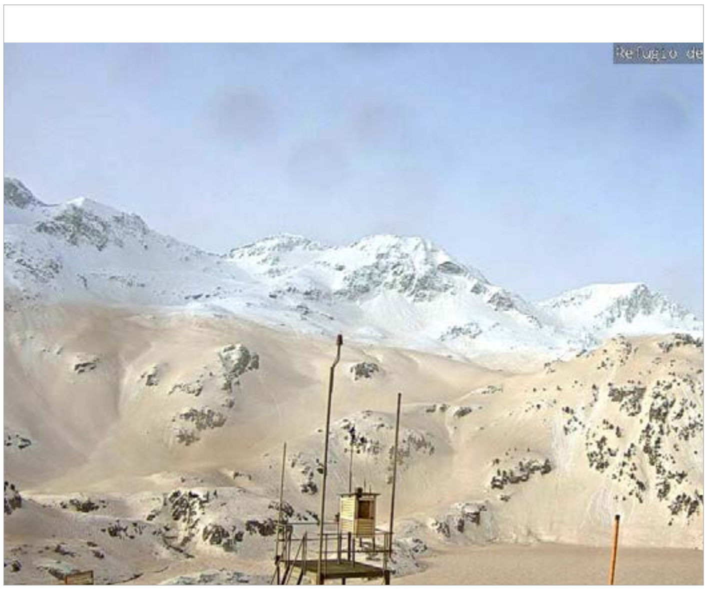

Figure 3. The Respomuso shelter in the Pyrenees (Spain) on 15 March 2022 at 0800 UTC.

Source: Photo provided by Albergues y Refugios: alberguesyrefugios.com convergence area at surface level which uplifted and transported the dust mass from Algerian deserts across the Atlas Mountains towards the Iberian Peninsula and western Europe. The year 2022 was characterized by a severe drought in the north of Morocco, Algeria and the Iberian Peninsula (Baruth et al., 2023). These dry conditions in North Africa favoured the intensity of the event.

Severe dust storm over the Middle East in May 2022

A remarkable synoptic-scale cut-off low dust storm occurred over Türkiye, Iraq, Jordan, the Islamic Republic of Iran, Kuwait, Bahrain, Qatar, Saudi Arabia and the United Arab Emirates, as well as the borders of Oman and Yemen, from 23 to 25 May 2022 (see Figure 4, where dust is identified by the colour pink). Moreover, on 25 May, the poorest Air Quality Index (AQI) value on record was registered in Tehran (Crisis 24, 2022), with a categorization of hazardous conditions in this city. This severe dust storm dramatically reduced the visibility all over the region. Low visibility resulted in transport disruption and negatively affected public health, especially among those suffering from respiratory diseases. Many flights were reportedly postponed due to the low horizontal visibility. Authorities also issued warnings regarding near lack of horizontal visibility in the worst affected areas. For instance, in Iraq, all flights across the country from early 23 May 2022 were suspended due to low visibility, and the Jordan Meteorological Department warned of low visibility due to dust, especially over the Badia Region. Moreover, the Kuwait Meteorological Department issued a red weather warning (which is the higher level on a two-tier scale) for dust and strong north-westerly winds of more than 60 km h^{-1}. Similarly, Saudi Arabia's National Center for Meteorology issued red dust storm warnings (the highest level on a three-tier scale) across the eastern Northern Borders Region and the far north-western part of the Eastern Region, and issued orange dust storm warnings (the second level on a three-tier scale) across the central Northern Borders Region and the far northern Eastern provinces on 23 May 2022.

The synoptic meteorological dust genesis mechanism (see Figure 4) was the formation of a deep, cut-off low over the eastern Mediterranean on 22 May 2022, accompanied by a considerably fast-moving upper-level trough over south-western Asia, causing instability and positive vorticity, especially over the region in front of the trough, until 25 May 2022.

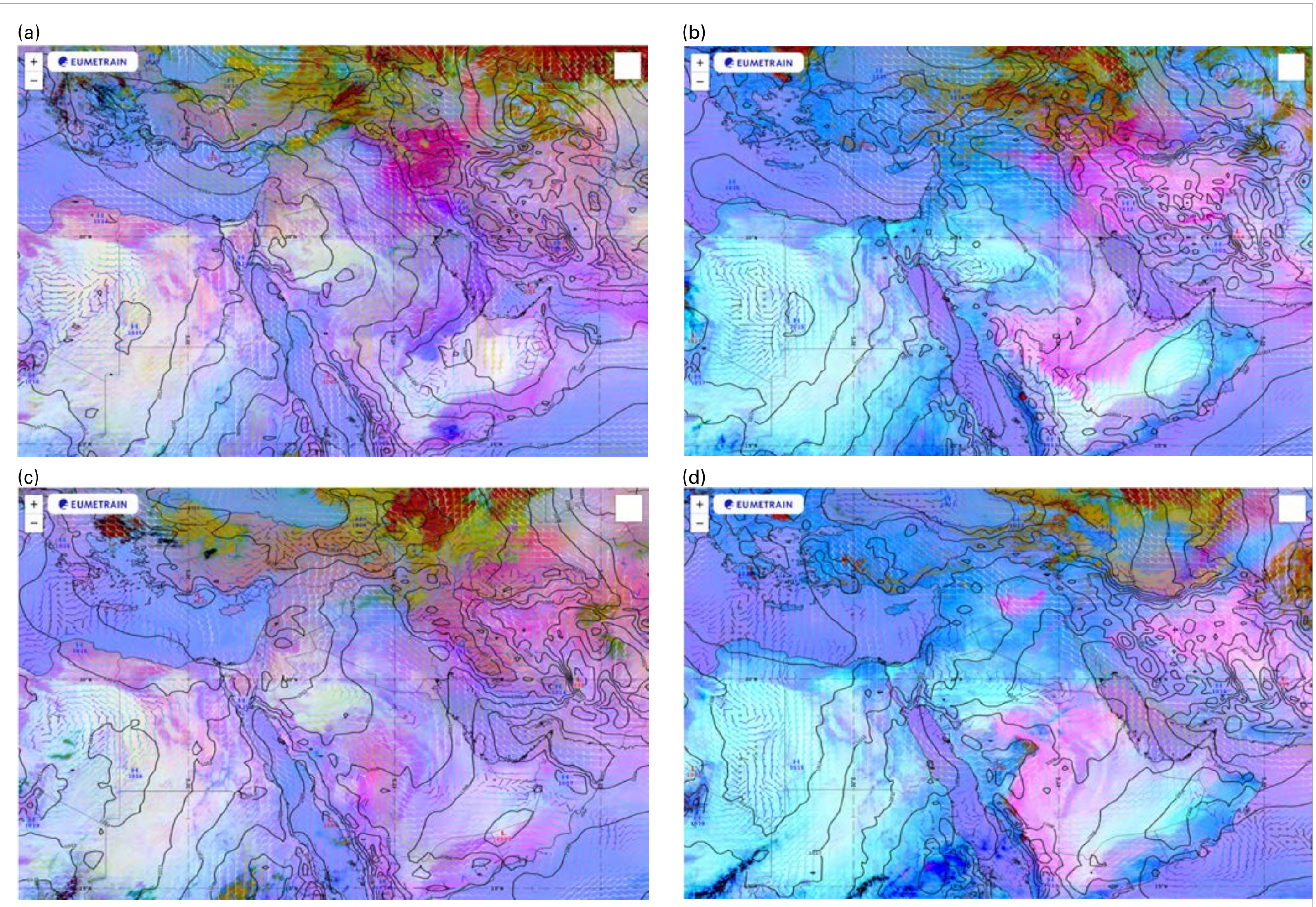

Figure 4. Meteosat RGB dust product, with dust shown in pink, 850 hPa wind vectors (m s^{-1}) shown with white arrows, and 1 000 hPa pressure contours shown with black lines, for (a) 24 May at 0000 UTC, (b) 24 May at 1200 UTC, (c) 25 May at 0000 UTC and (d) 25 May at 1200 UTC.
Source: EUMETSAT

Cropland dust storm in the eastern United States of America in May 2022

On 1 May 2022, an unusual dust storm, which originated from agricultural fields, killed 8 people, and injured 37 more in Illinois, United States (see Figure 5) (McCausland and Bush, 2023). Blowing dust reduced visibility to near zero on the Interstate 55 highway (I-55) near the Sangamon/Montgomery county line. According to Illinois State Police, 72 vehicles were involved on both sides of the I-55 between mile markers 76 and 78. Dust storms are more common in the south-western United States, and less so in the eastern United States, such as Illinois. During this dust storm, soil particles were emitted from freshly tilled and planted farm fields. This region had received less than normal precipitation in the months before. The large number of fatalities made this storm the third deadliest dust storm in the country. It was the first time that the eastern United States has seen such a devastating dust storm in recent decades.

Figure 5. As many as 80 vehicles were caught up in the massive crash on the I-55 on 1 May 2022.

Source: Photo courtesy of Nathan Cormier

Ongoing research

Climate change and dust emission

Sand and dust storms (SDSs) have a variety of impacts on society, ecosystems, weather and climate. Although SDS monitoring and forecasting accuracy has improved in recent years due to the progress of numerical models and observation systems, future projections that consider the interactions between SDSs and climate change are still unexplored.

Over the last decades, the Middle East region, where the Asian, African and European continents connect, has been greatly suffering from desertification processes and dust events at an alarming rate. The Middle East is in arid and semi-arid environments, affected by extensive dry climatic periods, intensive water withdrawals, and increasing and diverse anthropogenic pressure on hydrological resources. Because of the lack of in situ observations in the Middle East, satellites can support the identification of sources of SDSs in the region. The aerosol content gradient map from 2001 to 2023 (Figure 6) depicts that in the Middle East, the most significant hotspots in the growing trend of increased dust emissions are located along parts of the Afghanistan-Pakistan border, Lake Hamoon in the

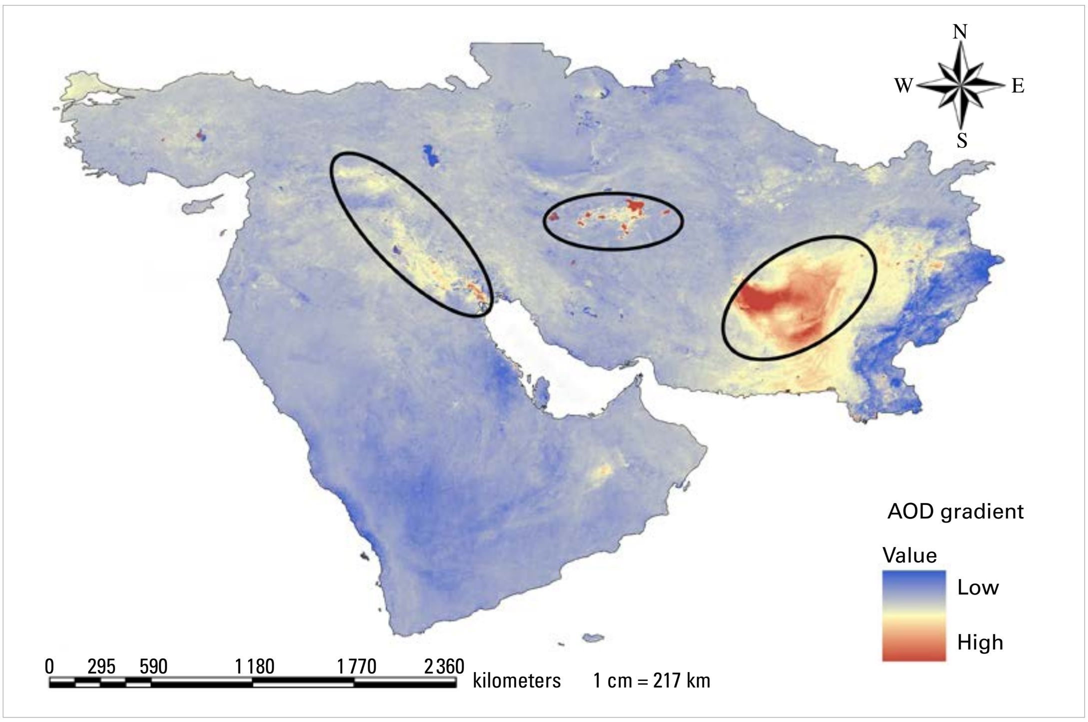

Figure 6. Aerosol content gradient (parameter considered is aerosol optical depth, AOD, at 550 nm) over the Middle East from 2001 to 2023. The red colours show the highest trend in dust emissions across the region. The black ellipses indicate the most significant hotspots in the area of the study.

Source: Results are based on the NASA moderate resolution imaging spectroradiometer (MODIS)/Terra and Aqua Aerosol Collection 6.1 product: https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MCD19A2. Data downloaded from: https://earthengine.google.com/.

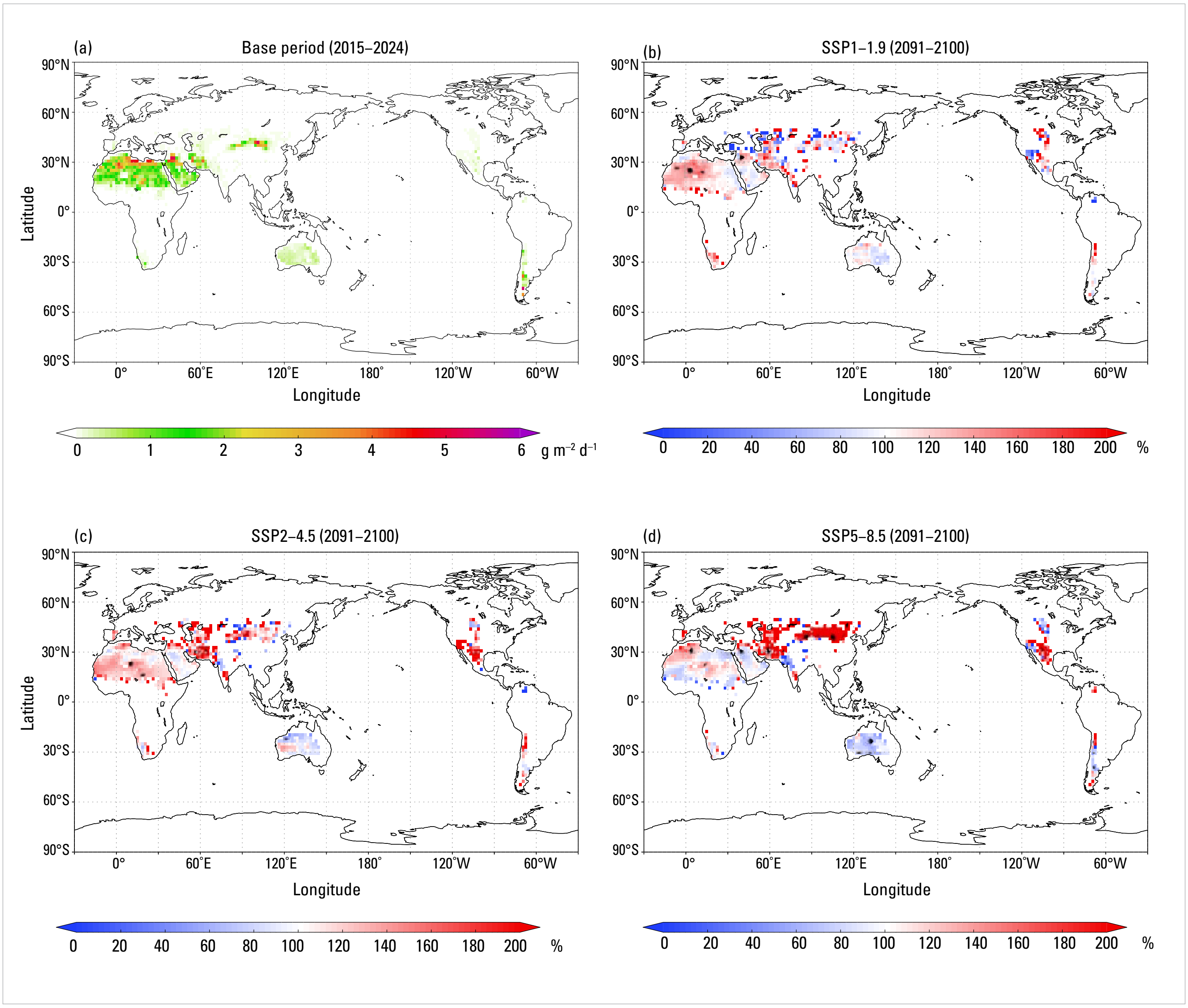

Figure 7. March average global SDS emissions for different climate scenarios using the Meteorological Research Institute Earth System Model. (a) Base period (2015–2024) average SDS emissions for all experiments (25 members). (b)–(d) Ratio between the base period (2015–2024) and future (2091–2100) average SDS emissions in the (b) SSP1-1.9, (c) SSP2-4.5, and (d) SSP5-8.5 scenarios. The average of five ensemble members is shown for each scenario. Blue colours indicate decreased emissions from the base period, while red colours indicate increased emissions from the base period. Shaded areas indicate statistically significant regions ($p < 0.05$ in t-test).

Source: Adapted from Maki et al. (2022)

Islamic Republic of Iran, the Mesopotamian Plain in Iraq, eastern Syrian Arab Republic, the lower reaches of the Tigris and Euphrates rivers close to the Persian Gulf, and the southern parts of Dasht-e Kavir in central Islamic Republic of Iran.

Some recent research has been undertaken to assess potential changes in global dust emissions. Maki et al. (2022) consider global emissions under three projected Shared Socioeconomic Pathway (SSP) climate warming scenarios. Figure 7 shows the spatial distribution of dust storm emissions for the month of March, when the effects of global warming were most pronounced. The difference between the base years (2015–2024) (Figure 7(a)) and the future years (2091–2100) for the three climate warning scenarios (Figure 7(b), (c) and (d)) shows that dust storm emissions are predicted to increase significantly during this period as warming progresses from the Gobi and Taklamakan deserts in eastern Asia to central Asia. In the Gobi Desert, the decrease in snow cover and increase in friction velocity due to warming is predicted to cause an increase in dust storm emissions during the month of March, and a similar mechanism can be assumed to occur in central Asia. In the Sahara, the effects of global warming may not be pronounced, in comparison with Asia, partly due to the limited snow cover in the Sahara. In the future, it will be necessary to advance our understanding of the mechanisms that are favourable to dust emission. Changes in the main global circulation and precipitation patterns associated with climate change interact with the occurrence of sand and dust storms.

Mineralogy in atmospheric composition forecasting systems

In most atmospheric composition forecasting systems, desert dust is represented as a single species. This approach is convenient, as it simplifies the task of simulating the dust life cycle and its radiative impact. However, it is clearly an important simplification as it is known that "mineral dust" really consists of several tens of individual mineralogical elements, which reflect the variety of the soils that are eroded by wind. Hematite and goethite are key for the assessment of the natural radiative forcing considered in climate change (Li et al., 2021). Feldspar, one of the dust mineralogical components, acts as a preferential ice nuclei. The surface concentration and deposition fluxes of some dust chemical components, as derived from the dust mineralogy, are also of interest as they have a significant impact on various ecosystems. For example, dust iron deposition is a key element for marine life. As a consequence, the representation of dust mineralogy has been the subject of an increased focus in the past years (see, for example, Menut et al., 2020, Myriokefalitakis et al., 2022 and Gonçalves Ageitos et al., 2023, among others).

Recently, the Integrated Forecasting System (IFS), the core of the Copernicus Atmosphere Monitoring Service (CAMS), has been extended in an experimental version to prognostically simulate 12 mineralogical components of dust (Rémy et al., 2022). The chemical composition of dust can be derived from the mineralogical information, which allows for comparison against surface observations, notably of iron, as shown in Figure 8. Each of the dust mineralogical components uses specific optical properties. The mineralogical and chemical composition of global dust was simulated over four years and evaluated against surface observations over the United States and Europe, as well as against other simulated values such as those from Myriokefalitakis et al. (2018). This evaluation showed the model's capacity to forecast dust mineralogy and this in turn will improve our knowledge of the radiative impact of dust mineralogical components, as well as the representation of dust-related species of interest such as iron and phosphorus.

In order to better understand the emissions of dust mineralogical components, in July 2022, NASA launched the Earth Surface Mineral Dust Source Investigation (EMIT) mission. EMIT aims to collect data on the colour and mineral composition of Earth's dry and dusty regions by using imaging spectroscopy. This data set will allow for the provision of global mineralogical databases, which can then be used in global atmospheric composition models to improve the representation of dust mineralogical composition.

Advances on probabilistic forecasts

To provide more accurate SDS forecasts (that is, on short-term scales), probabilistic approaches based on model ensembles can derive products that are more robust and overall better quality than individual models, particularly for extreme events. The Korea Meteorological Administration (KMA) has been developing an ensemble prediction system, based on the Asian Dust Aerosol Model (ADAM), which generates probability forecasts of Asian dust for PM_{10} (Kim et al., 2023). Dust crisis levels are categorized using a risk matrix of PM_{10} concentrations of 150, 300 and 800 μg m^{-3}, and occurrence probabilities of 20%, 40% and 60%. These thresholds follow the thresholds established by the Ministry of Environment of the Republic of Korea. Additionally, crisis information is provided for each administrative district in the Republic

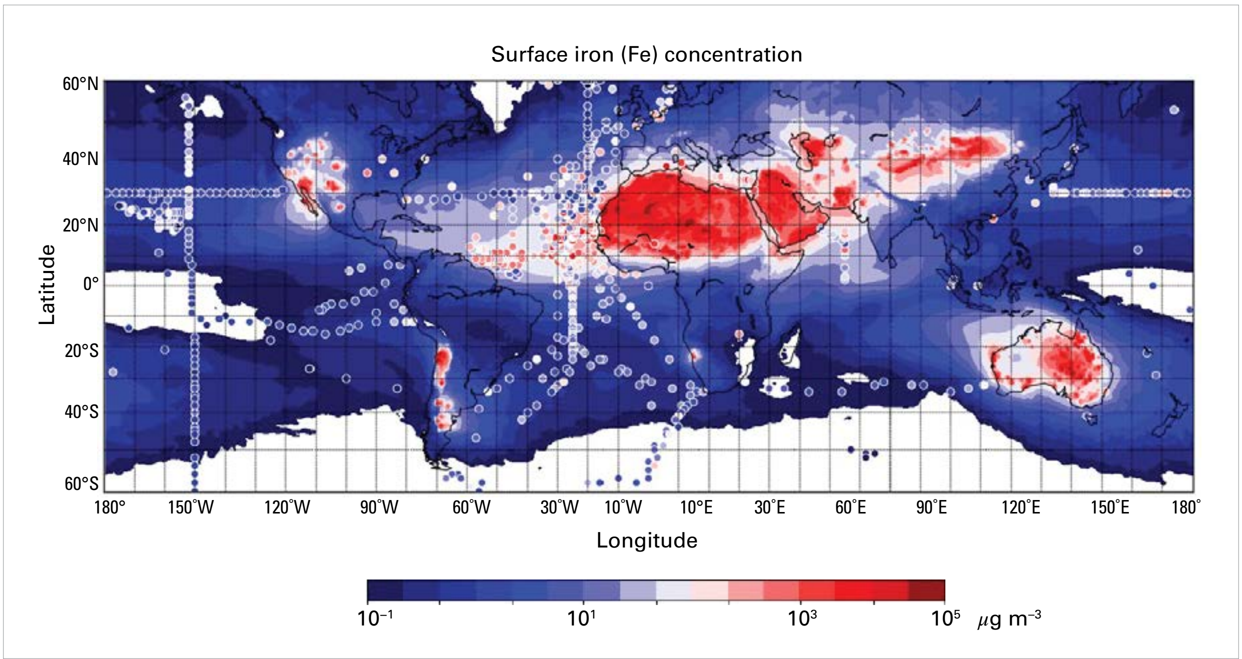

Figure 8. Climatological observations of surface iron (Fe) concentration, as gathered by Hamilton et al. (2019) (shown by circles), as compared against values simulated by an experimental version of the IFS (shown by contours)

Source: European Centre for Medium-Range Weather Forecasts (ECMWF)

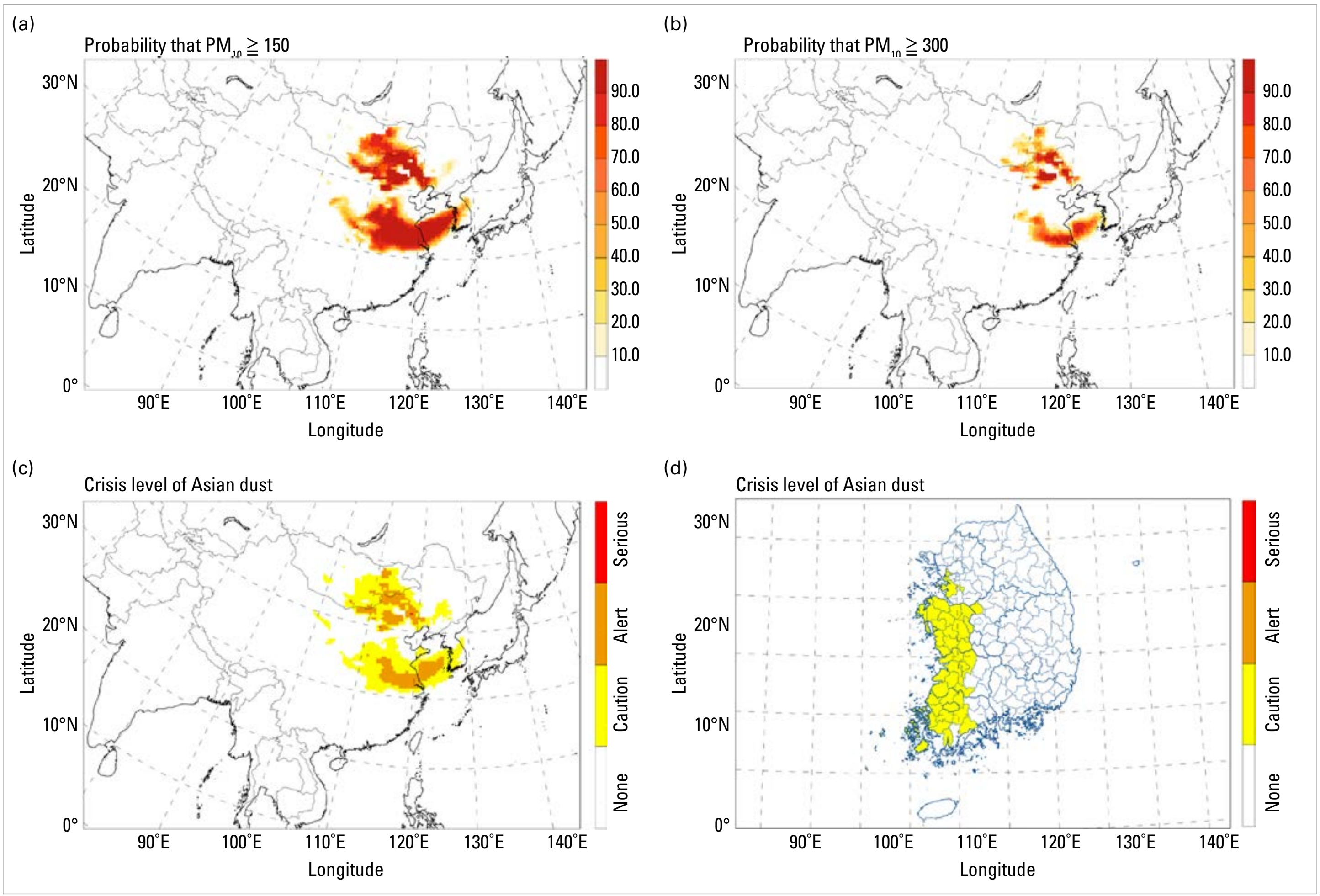

Figure 9. ADAM3-EPS probability (%) prediction for 7 May 2021 at 0600 UTC: (a) $PM_{10} \geq 150\ \mu g\ m^{-3}$, (b) $PM_{10} \geq 300\ \mu g\ m^{-3}$, (c) crisis-level information over East Asia, and (d) crisis-level information for each administrative district in the Republic of Korea

Source: Adapted from Kim et al. (2023)

of Korea (see Figure 9). This new probabilistic ensemble system (called the Asian Dust Aerosol Model 3-Ensemble Prediction System, (ADAM3-EPS)) is expected to improve valuable references for the prediction and analysis of Asian dust event forecasting.

Other news

Mapping health and safety effects of airborne dust in Pan-American and beyond

Dust is a hazard and growing concern in aviation, both military and civilian. Dust storms reduce the recreational value of landscapes, decrease performance of solar power plants and spread human pathogens, all of which negatively affect local and regional economies. The loss of soil nutrients is a cost to agriculture of more than 8 billion dollars every year. A team of 28 dust experts, coordinated by the WMO Sand and Dust Storm Warning and Advisory System (SDS-WAS) Pan-American Node, has published a comprehensive review of dust hazards for the Pan-American region and beyond (Tong et al., 2023b). Tong et al. (2023b) have constructed the first map of dust vulnerability in the Americas, with foci on health and safety effects, for researchers and policy makers to better appreciate the global, regional and local context for dust as a health and safety hazard (Figure 10).

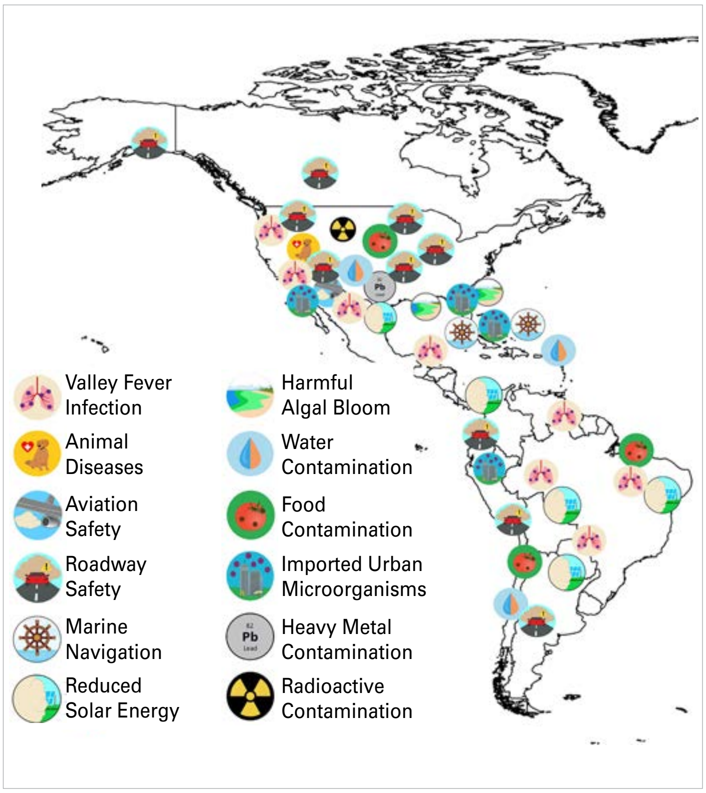

Figure 10. Summary of health and safety effects of airborne dust in the Pan-American region

Source: Tong et al., 2023b

Exposure to dust particles has been associated with adverse health effects, including heart attacks, cardiovascular mortality, lung cancer and Valley fever. In the Americas, one of the most documented and striking effects of soil dust is the mysterious spread of Coccidioidomycosis, commonly known as Valley fever, an infection caused by inhalation of soil-dwelling fungi unique to the Americas. The United States Centers for Disease Control and Prevention (CDC) reports that the incidence rate of Valley fever has increased by 700% from 1998 to 2011 in the same regions frequented by dust storms. Dust storms are well known major safety hazards to transportation, especially motor vehicles travelling on dust-affected roadways. Although small and short-lived, local dust storms are responsible for many fatal highway accidents. After extreme heat and flooding, dust storms are the third largest cause of weather fatalities in Arizona, where 157 people were killed and 1324 injured on highways between 1955 and 2011.

A recent study shows that there was a total of 232 deaths in the United States from windblown dust events from 2007 to 2017 (Tong et al., 2023a). This number is 20-fold more than that reported by the National Oceanic and Atmospheric Administration (NOAA) Natural Hazard Statistics database. This is partly because dust events associated directly with thunderstorms have apparently been excluded from databases in the United States (Ardon-Dryer et al., 2023) and Australia (O'Loingsigh et al., 2010). In addition, many weather observations nowadays are made by automated systems which may be able to discern reduced visibility, but not its cause. Other observations are still taken by human observers, but these observers are not always consistent with each other in their notations. As a result, the Natural Hazard Statistics database has missed many dust cases and assigned many dust fatalities to high wind and thunderstorm conditions (~45%). The study by Tong et al. (2023a) emphasizes that it is essential to ensure accurate and consistent international recording of SDSs and related weather phenomena in meteorological observations and databases for supporting assessment studies. The study also finds that in most years, dust events caused a comparable loss of life to that from other weather hazards such as hurricanes, thunderstorms, lightning and wildfires. Dust fatalities are most frequent over the south-west of the United States, consistent with the spatial distribution of dust storm occurrences. Other high-risk regions include the Colorado Plateau, Columbia Plateau in Washington and Oregon, the High Plains, where the disastrous "Dust Bowl" drought event occurred, and the Corn Belt where blowing dust from croplands presents a hazard to driving.

Association for Aerosol Studies in Latin America and the Caribbean

In late 2022, researchers in South and Central America launched the regional Association for Aerosol Studies in Latin America and the Caribbean (ALACEA). This new initiative aims to help foster and consolidate the community working in the different countries in the region, and will be put forward to be part of the International Aerosol Research Assembly (IARA). IARA is an organization consisting of national, regional and special-interest aerosol research associations.

Monitoring dust events in India through an Indio-American collaboration

Through a collaboration between Chapman University (United States) and Central University Ajmer (India), efforts are being made to monitor dust events, air quality and meteorological parameters on the campus of Central University Ajmer in Rajasthan. Dust storms (locally known as "Aandhi") are very frequent over the northern parts of India during the pre-monsoon season (March–July). Some of the dust is from local sources (namely, the Thar Desert and the Rann of Kutch) and some of the dust is from long-range transport from the Arabia Peninsula. Sometimes, the dust takes a track over the Arabian Sea, entering through the Gujarat coast, and reaches the northern parts of the Himalayas, blanketing the snow and glaciers of the Himalayan region. The mineralogical analysis of dust considered in this new Indio-American collaboration will provide insight into the study of the radiation budget and impacts of dust on the atmosphere that will further support the development of dust forecast systems in India (in turn supporting socioeconomic activities such as tourism). It will also advance understanding of the atmospheric drivers (such as the frequency of cyclones in the Indian Ocean) that favour the long-range transport of Arabian dust to India.

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WMO SDS-WAS websites and contacts

WMO SDS-WAS:
https://community.wmo.int/en/activity-areas/gaw/science-for-services/sds-was
Email: gaw@wmo.int

Barcelona Dust Regional Centre, SDS-WAS Regional Centre for Northern Africa, Middle East and Europe (NAMEE):
http://dust.aemet.es
Email: dust@aemet.es

Beijing Dust Regional Centre, SDS-WAS Regional Centre for Asia:
http://www.asdf-bj.net/
Email: xiaoye@cma.gov.cn

Barbados Dust Regional Centre, SDS-WAS Regional Centre for Pan-Americas:
http://sds-was.cimh.edu.bb/
Email: asealy@cimh.edu.bb

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All authors (in alphabetical order)

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